ON PLANNING OF REPAIR OF PRESSURISED MAIN PIPELINES BASED ON THE RESULTS OF IN-PIPE DIAGNOSTICS[*]

A.S. MILENIN
E.O. Paton Electric Welding Institute, NASU
11 Bozhenko Str., 03680, Kiev, Ukraine. E-mail: office@paton.kiev.ua

The world and national practice of operation of land main pipelines shows the trend to utilisation of different methods to repair them by welding without any interruption of transportation of a product. Planning of a certain repair method, which is an important stage of ensuring the efficiency and safety of restoration of a carrying capacity of defective regions in main pipelines, requires development of appropriate methodological principles for analysis of damage of a structure, estimation of admissibility of operation and prediction of remaining life. This study suggests a multilevel procedure for numeric analysis of results of in-pipe diagnostics of the state of linear parts of main pipelines, allowing for the specific character of repairing them without removal from service, and permitting optimisation of repair-and-renewal operations in lengthy regions of a pipeline on the basis of numeric ranking of defects of a different nature. It is suggested using different levels of ranking depending on the available data of technical diagnostics of the state of a specific linear region of a main pipeline: based on subdivision of all defects into admissibility groups by estimating the remaining safety factor in a region of a specific defect, or by calculating the probability of violation of integrity of a pipeline wall. A differing degree of conservatism of the suggested procedure depending on the completeness of the source data makes it possible to analyse the results of in-pipe diagnostics at the required accuracy and effectively plan removal of the detected defects by the methods of repair of pipelines without withdrawing them from service. 12 Ref., 10 Tables, 5 Figures.

Keywords: *main pipeline, repair without removing from service, in-pipe diagnostics, defect, planning, ranking*

Application of different methods for repair of main pipelines (MP) without removing them from service is one of the modern approaches to maintaining their serviceability. An interest in such technologies is caused, first of all, by economic benefits and an insignificant negative impact on the environment. In addition, this allows a long-term planning of local repair operations, which makes it possible to continuously maintain the safe operation of a pipeline at the required level [1–3].

Performing repair operations in active MP is associated with the following characteristic technological and methodological problems [4]:

- planning of local repair operations in lengthy regions of MP with a different degree of service damage in terms of minimisation of the risk of emergency situations;
- selection of repair parameters from the standpoints of ensuring safety of the repair operations performed on a pipeline under internal pressure;
- ensuring serviceability of regions of MP, the carrying capacity of which was restored by the repair methods without removal from service.

These problems should be solved in an integrated manner by including both development of new methodological principles of planning and optimisation of repair parameters, and implementation of science-intensive technologies for repair of defective regions of pressurised MP. Modern regulatory documents and practical recommendations are oriented primarily to overhaul of defective land MP, which does not allow taking into account the specific character of repair under pressure and effectively planning the repair-and-renewal operations, in particular, on the basis of results of in-pipe diagnostics (IPD) of the state of linear regions of MP. Such specific features include the problems of ranking of the defects detected during the IPD process, allowance for the natural spread of the available data on sizes and positions of defects and actual properties of metal of a pipeline, and selection of a repair method based on the maximal service life of a repaired structure. To allow for the characteristic

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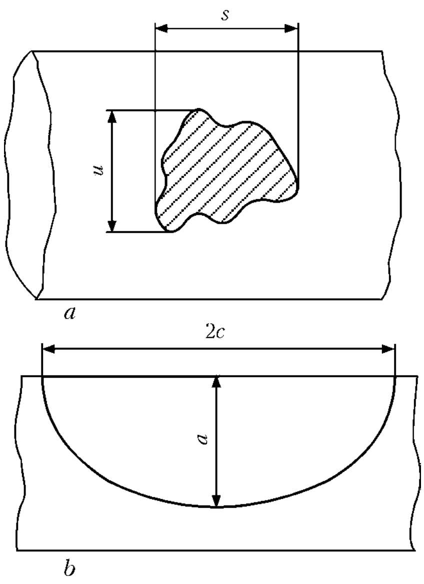


Figure 1. Schematic of defects of the type of local corrosion metal losses (*a*) and crack-like defects (*b*)

peculiarities of planning of the repair-and-renewal operations on MP without removing them from service, the E.O. Paton Electric Welding Institute of the NAS of Ukraine developed a multilevel procedure for ranking of the defects detected in technical diagnostics.

The main defects in MP are defects of the type of metal discontinuity of a corrosion or stress-corrosion nature (local and general loss of metal, stress-corrosion cracks), defects in welds (lacks of penetration, pores), and shape defects (dents) [5]. Their admissibility is specified by different national and industry standards, as well as codes based on deterministic criterion relationships. In this case, different safety and reliability factors [6–8] are used to allow for stochastic deviations of source data from the known values, this being a maximum conservative approach. For example, the limiting state of a MP region containing a defect of the corrosion thinning type (Figure 1, *a*) can be estimated on the basis of the deterministic criterion [9]

$$Y = t_{\min} - W\Delta t - t_{\mathrm{p}} R_{\mathrm{t}}, \qquad (1)$$

where $t_{\min}$ is the minimal residual thickness of the MP wall; t_{p} is the minimal admissible thickness of the MP wall determined either by design-service requirements to MP in a region under consideration, or by additional calculations; Δt is the time period under consideration; W is the uniform corrosion rate (conservatively, can be assumed to be equal to 1 mm/year); R_{t} is the shape function of the thinning defect determined as follows (see Figure 2, *a*):

$$R_{\mathrm{t}} = \begin{cases} 0.2 \text{ at } \lambda = \dfrac{1.285 s}{\sqrt{D t_{\mathrm{p}}}} \le 0.3475, & (2) \\ \left(0.9 - \dfrac{0.9}{\sqrt{1.0 + 0.48\lambda^2}}\right)\left(1.0 - \dfrac{0.9}{\sqrt{1.0 + 0.48\lambda^2}}\right)^{-1} & \\ \text{at } \lambda > 0.3475, & \end{cases}$$

where D is the inner diameter of a pipe.

Term $Y > 0$ guarantees integrity of the defective region of MP under the considered conditions.

The most common deterministic criterion of admissibility of a crack-like defect (Figure 1, *b*) is the two-parameter criterion of brittle-tough fracture (Figure 2, *b*) having the following expression [10]:

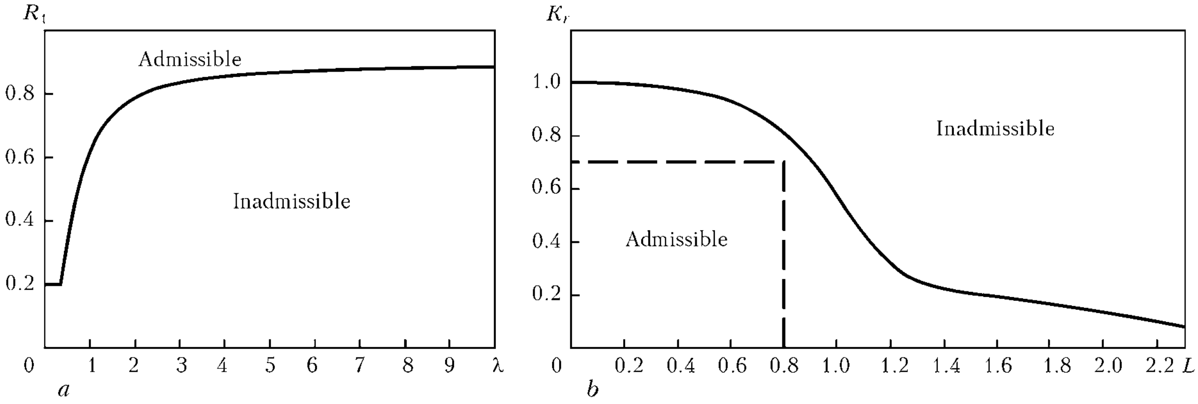
$$Y = f(L_r) - K_r, \qquad (3)$$

where

$$f(L_r) = \begin{cases} (1 - 0.14 L_r^2)[0.3 + 0.7 \exp(-0.65 L_r^6)] \\ \text{at } L_r \le L_r^{\max} = \dfrac{\sigma_{\mathrm{t}} + \sigma_{\mathrm{y}}}{2\sigma_{\mathrm{y}}}, \\ 0 \text{ at } L_r > L_r^{\max}; \end{cases} \qquad (4)$$

$$K_r = \frac{K_I}{K_{IC}}; \quad L_r = \frac{\sigma_{\mathrm{ref}}}{\sigma_{\mathrm{y}}};$$

K_I is the stress intensity factor at a given point of contour of the surface semi-elliptical crack; and σ_{ref} is the reference stress in a defect region,



a *b*

Figure 2. Criterion diagrams of admissibility of defects of the type of local corrosion metal losses (*a*) and crack-like defects (*b*)

Table 1. Selection of method for repair of defective regions in MP depending on the degree of development of damage [8]

Nature of defect and parameter	Repair method
Corrosion-mechanical damages:	Grinding
external $a \le 0.2t$	Mounting of reinforcing structure
external $0.2t < a \le 0.5t$	Same
external $0.5t < a \le 0.8t$	»
external $a > 0.2t$; $t_{\min} \ge 5$ mm	»
external $s \le 100$ mm or group of closely located pits $a > 0.4t$	»
defects extending in circumferential direction $a > 0.2t$; $s \ge 1/6\pi D$	»
in zone of circumferential welds $a > 0.4t$	»
internal $a > 0.2t$	»
Cracks:	»
external $a < 0.2t$; $2c \le 2\sqrt{Dt}$	Grinding

whose calculation procedure is described, in particular, in study [11].

Therefore, term $Y > 0$ is sufficient for the guaranteed admissibility of the defects under consideration.

In analysis of admissibility of the crack-like defect, after a certain period of time Δt it is necessary to make allowance for the probability of growth of the crack, namely:

$$\begin{cases} a(\Delta t) = a_0 + V_a \Delta t, \\ c(\Delta t) = c_0 + V_c \Delta t, \end{cases} \tag{5}$$

where a_0 and c_0 are the initial sizes of the crack; V_a and V_c are the rates of growth of the crack along the respective size, which can be estimated as follows:

$$V_{a,\,c}(K_I) = \begin{cases} V_{\max} & \text{if } K_I \ge K_{ISCC}; \\ 0 & \text{if } K_I < K_{ISCC}, \end{cases} \tag{6}$$

where $V_{\max}$ is the maximal rate of growth of the crack determined from the diagram of static corrosion resistance of a material under given conditions.

It should be noted that, compared to the mentioned deterministic approaches, the use of the probability procedures to analyse the state of defective regions in MP allows correctly describing the probable spread of values of the source data based both on the existing experience in investigations of defective pipeline systems and on the technological characteristics of the applied equipment and specifics of the analysis.

The main methods for repair of pressurised MP are controlled grinding of surface defects, welding-up of the surface defects, and mounting of reinforcing structures (sleeves, bands) [12]. The choice of the repair technology is based on the degree of damage of a pipeline, as well as on the efficiency of each specific method. Approaches specified in the actual regulatory documents [8] (Table 1), in particular, can be conservatively used for this purpose. To reduce conservatism of selection of a repair method, it is possible to model the repair process at specific technological parameters, and, on the basis of corresponding safety criteria, efficiency requirements and sufficient service life of the repaired region, to conclude on the possibility of using this or other method by restoring the carrying capacity of a defective structure.

As proved by practice, the quantity of geometric anomalies detected by IPD using flaw detectors may amount to several thousands (Figure 3). The order of their repair based on the existing deterministic regulations, which subdivide defects into certain groups by the degree of danger (up to four), may be ambiguous in a case of a large quantity of defects, because of the necessity to rank geometric anomalies within one group. Therefore, when planning repair of MP without its removal from service it is reasonable

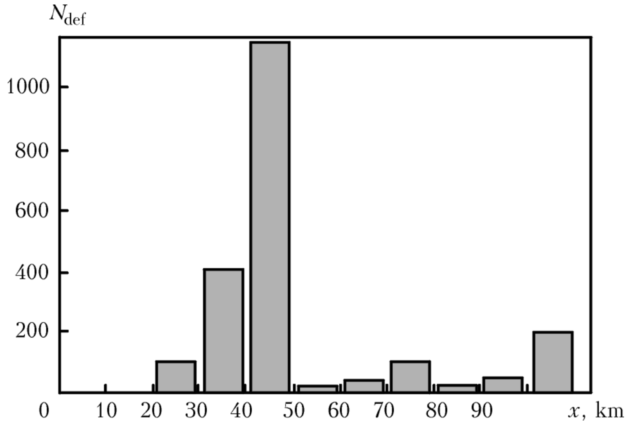


Figure 3. Diagram of distribution of the quantity of metal loss defects N_{def} according to the data of IPD of part of the «Urengoy-Centre 2» main gas pipeline

to use continuous ranking. Within the framework of the developed procedure, it is suggested using the following levels of estimation of the order of removing defects depending on the completeness of the available data and required conservatism:

- *level 1*. Subdivision of all defects into four groups as to their admissibility degree: insignificant, moderate, significant and critical;
- *level 2*. Estimation of the safety factor for the MP region containing a detected specific defect;
- *level 3*. Calculation of the probability of fracture of the pipeline wall within the zone of the considered defect.

According to ranking level 1, all the defects detected by IPD of a linear part of MP are subdivided into four groups by the degree of admissibility, according to National Standard DSTU-N BV.2.3-21:2008. In this case the priority of repair is determined by belonging to a group of the most dangerous defects. This approach is applied if all moderate defects can be technically removed in a period of up to six months, and significant defects — in a period of up to two months. The presence of critical defects provides for changing service conditions of a pipeline up to its complete shutoff. The determining parameter is safety factor n, which is calculated on the basis of the criterion of admissibility of the state of a region containing the certain type of a defect.

The safety factor for a 3D defect of the type of a local corrosion loss of metal is estimated on the basis of a modified diagram of the limiting state of a region (Figure 4, *a*), where function R_τ determined by normalising of function R_t has the following form:

$$R_\tau = \frac{1}{3.87R_t} - 0.292. \qquad (7)$$

If the state of a defect is described by position A_1 in the diagram, the safety factor is determined by relationship

$$n = \frac{OA_1}{OA_2}. \qquad (8)$$

The length of segment OA_2 is determined either graphically or by numeric solution of the following equation with respect to coordinate λ of point A_2:

$$\frac{R_\tau^{A_1}}{\lambda^{A_1}}\lambda - R_\tau(\lambda) = 0. \qquad (9)$$

Safety factor for the crack-like defect is determined similarly to the above approach for the local corrosion loss of metal, but the limiting state curve in this case is a two-parameter diagram of admissibility of cracks (Figure 4, *b*). The safety factor is estimated by relationship of lengths of the segments according to formula (8). The length of segment OA_2 is determined either graphically or by numeric solution of the following equation with respect to coordinate L_r of point A_2:

$$\frac{K_r^{A_1}}{L_r^{A_1}}L_r - K_r(L_r) = 0. \qquad (10)$$

For the MP defects of a different degree of admissibility the ranges of the values of safety factor n are as follows [6]:

$n > k$ — insignificant;
$1.1\sigma_t/\sigma_y \le n < k$ — moderate;
$1.1 \le n < 1.1\sigma_t/\sigma_y$ — significant;
$n < 1.1$ — critical,

where $k = 0.9k_1k_{app}/m$; m is the service factor of a pipeline; k_1 is the material reliability factor; k_{app} is the reliability factor of the pipeline for its application.

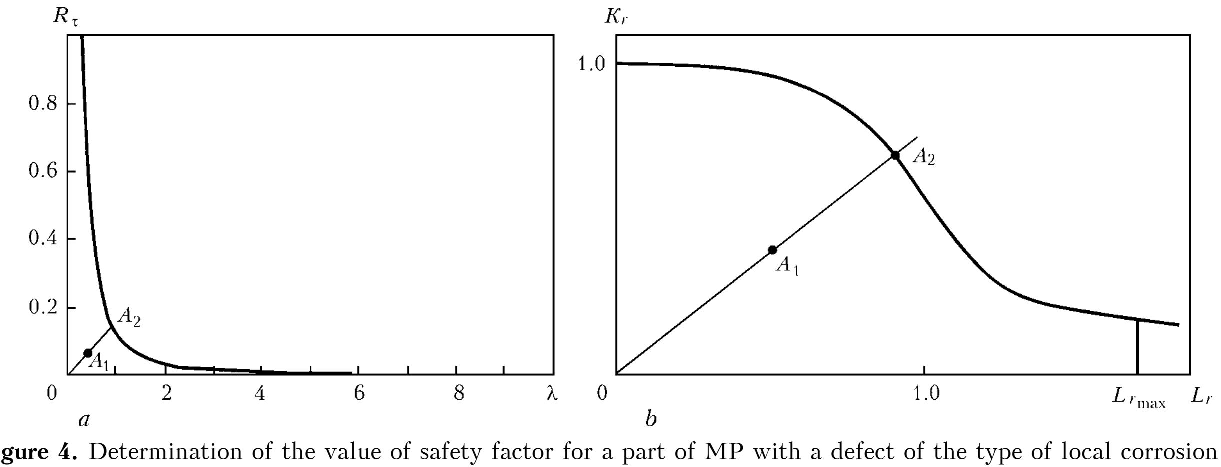


Figure 4. Determination of the value of safety factor for a part of MP with a defect of the type of local corrosion loss of metal (*a*) and crack-like defect (*b*)

The first stage of ranking level 2 repeats level 1, according to which all the defects are subdivided into four groups by the degree of their admissibility at the time of their diagnostics. All the defects ranked as insignificant, moderate or significant are subject to planning of repair. Ranking within these groups is performed on the basis of the value of the calculated safety factor allowing for a natural growth of defects by using the corresponding procedures. Consideration of repair of critical defects is based on a certain change in service parameters of the defective region of MP (decrease of internal pressure) and transfer of a defect to a rank of significant or moderate. The priority of removal of each isolated (united) defect is based on minimisation of the determined values of the safety factor under specific service conditions: the lower the safety factor of the defective region, the higher is the priority of its repair.

Ranking level 3 is least conservative and makes it possible to allow for a natural spread of the source data in order to more accurately determine the order of removal of defects, which may change the admissibility degree within the considered period, as well as in a case of the insufficient information on geometric and service parameters of the defective region and/or mechanical characteristics of a pipeline material. In this case the ranking parameter is the probability of an emergency situation in the defective region under real service conditions, which is calculated by the Monte-Carlo method using the following algorithm:

- proceeding from the known densities of distribution of the source data, representative sampling of their specific values is found within the known variation ranges; it is assumed in this case that the probability of characteristic of a defect is random and varies from 0 to 1. Note that the representative sampling implies quantity N_s of equally probable combinations, which is sufficient for a stable value of the probability of fracture of a specific defect according to the chosen limiting state criterion;
- based on the deterministic criteria of fracture, the admissibility of a detected defect is determined for each set of geometric and service characteristics out of the representative sampling;
- calculation of the quantity of inadmissible states of a pipeline with specific defect N_i is made within the representative sampling. Therefore, the probability of the emergency situation, P_i, in a region of the isolated or plural defect implies relationship $P_i = N_i/N_s$;
- if necessary, the total probability of the emergency situation, $P_\Sigma = 1 - \Pi(1 - P_i)$, in a MP region with independent defects is determined to reveal the priority repair region.

Allowance for a stochastic deviation of values of different source data is described by using a truncated normal distribution (geometric sizes of a defect, strength properties of a pipeline material, corrosion rate) and Weibull distribution (crack resistance characteristics of a material). The order of repair at each time moment after diagnostics of the state of a linear MP region is determined by probability P_i: the higher the probability of the emergency situation, the higher is the repair priority.

The given methodology of analysis of the data base on the defects detected in IPD of the MP state was implemented in the form of a graphical user software package. Ranking of model defects in terms of the order of repair under pressure was performed as an example of its application (Table 2). Geometric and service parameters of the investigated linear part of MP are as follows:

Segment length L, m	2000
Internal diameter D, mm	1420
Wall thickness t, mm	20
Minimal admissible wall thickness $t_{\min}$, mm	16
Pipeline material, steel 17G1S, MPa	$\sigma_y = 360$ $\sigma_t = 510$
Pressure at investigated region inlet $P_{\max}$, MPa	7.5
Pressure at investigated region outlet $P_{\min}$, MPa	6.5
Corrosion rate, mm/year, in region of:	
0–800 m	0.2
800–1400 m	0.4
1000–2000 m	(conservatively assumed value is 1)
There are no regular loads caused by imperfection of geometry of the considered region	

The results of calculation of the ranking parameters according to the suggested procedure for the model defects allowing for their development during further operation of MP at different time moments are given in Tables 3–6, respectively, and the priority of repair of each of the defective regions of MP according to different ranking levels is given in Table 7. It should be noted that the method of repair of a specific MP region determined according to Table 1 can be changed during development of a defect, and limiting values of the sizes within the specific repair method can serve as a reference for determination of the terms of repair from the standpoint of minimisation of costs and labour intensity of repair, whereas the ranking parameters make it possible to determine only the sequence of removal of defects.

It can be seen from distribution of the total probability of defects on a 10 m repair base determined according to level 3 and shown in Figure 5 that removal of all defects in the two,

Table 2. Parameters of model defects in linear part of MP

Defect No.	Type of defect	Position of defect		Size of defect, mm			Internal pressure in defect region of MP, MPa
		In length, m	In circumference, deg	Axial	Tangential	Radial	
1	Thinning	150	30	160	17	4.7	7.4
2		230	0	200	20	7	7.4
3		680	120	60	8	5	7.2
4		681	60	100	10	15	7.2
5		800	40	120	11	14.7	7.1
6		1150	90	80	15	8	6.9
7		1200	80	25	7	10	6.9
8		1200	10	35	5	13	6.9
9		1200	120	170	13	6	6.9
10		1370	0	95	11	15	6.8
11		1560	140	150	18	6	6.7
12		1710	30	50	26	9	6.7
13		1750	90	75	16	8	6.6
14		1780	0	45	8	8	6.5
15	Longitudinal crack	530	50	25	–	2	7.2
16		710	110	15	–	2	7.2
17		750	30	10	–	3	7.1
18		1100	70	6	–	1	7.0
19		1520	20	20	–	2	6.7

Table 3. Parameters of ranking of model defects and repair method at the time moment of diagnostics of MP

Defect No.	Admissibility group	Safety factor	Probability of fracture	Repair method
1	Insignificant	1.648299	0.011	Grinding
2	Critical	0.885463	0.4	Welding-up
3	Insignificant	2.933383	0	Grinding
4	Critical	0.666297	0.983	Welding-up
5	Same	0.603503	0.621	Same
6	Significant	1.523807	0.035	»
7	Insignificant	2.610481	0	Grinding
8	Same	1.618357	0.0777	Same
9	Significant	1.340008	0.198	Welding-up
10	Critical	0.694965	0.969	Same
11	Insignificant	1.626517	0.125	Grinding
12	Same	1.893557	0.003	Same
13	»	1.686921	0.0255	»
14	»	2.391991	0	»
15	Significant	1.534515	0.06273	Welding-up
16	Insignificant	1.540512	0.04391	Grinding
17	Significant	1.463110	0.116	Welding-up
18	Insignificant	1.730804	0.005535	Grinding
19	Same	1.651180	0.0246	Same

Table 4. Parameters of ranking of model defects and repair method after 1 year in service

Defect No.	Admissibility group	Safety factor	Probability of fracture	Repair method
1	Insignificant	1.552745	0.02	Grinding
2	Critical	0.859123	0.43	Welding-up
3	Insignificant	2.756573	0	Grinding
4	Critical	0.652421	0.992	Mounting of sealing sleeve
5	Same	0.592111	0.646	Welding-up
6	Significant	1.439648	0.0695	Same
7	Insignificant	2.511972	0	Grinding
8	Same	1.547994	0.0837	Same
9	Significant	1.224116	0.25	Welding-up
10	Critical	0.669225	0.985	Grinding
11	Significant	1.254279	0.273	Welding-up
12	Insignificant	1.699346	0.028	Grinding
13	Significant	1.478064	0.0857	Welding-up
14	Insignificant	2.073059	0.00125	Grinding
15	Significant	1.364442	0.3641	Welding-up
16	Same	1.356944	0.22386	Same
17	»	1.291293	0.2952	»
18	»	1.484581	0.09594	»
19	»	1.453562	0.18819	»

Table 5. Parameters of ranking of model defects and repair method after 2 years in service

Defect No.	Admissibility group	Safety factor	Probability of fracture	Repair method
1	Significant	1.465154	0.0365	Welding-up
2	Critical	0.839193	0.457	Same
3	Insignificant	2.622561	0	Grinding
4	Critical	0.638599	0.992	Mounting of sealing sleeve
5	Same	0.580757	0.672	Welding-up
6	Significant	1.371563	0.0963	Same
7	Insignificant	2.413463	0	Grinding
8	Significant	1.477631	0.162	Welding-up
9	Same	1.129953	0.309	Same
10	Critical	0.630616	0.995	Mounting of sealing sleeve
11	Same	1.060068	0.429	Welding-up
12	Significant	1.529412	0.608	Same
13	Same	1.317405	0.182	»
14	Insignificant	1.860438	0.0085	Grinding
15	Significant	1.180542	0.7651	Welding-up
16	Same	1.285151	0.51537	Same
17	Critical	1.091123	0.7515	»
18	Significant	1.310414	0.30134	»
19	Same	1.256049	0.37066	»

Table 6. Parameters of ranking of model defects and repair method after 3 years in service

Defect No.	Admissibility group	Safety factor	Probability of fracture	Repair method
1	Significant	1.393489	0.0632	Welding-up
2	Critical	0.819303	0.486	Same
3	Insignificant	2.489434	0	Grinding
4	Critical	0.624833	0.997	Mounting of sealing sleeve
5	Same	0.569441	0.689	Same
6	Significant	1.319313	0.145	Welding-up
7	Insignificant	2.364209	0.0005	Grinding
8	Significant	1.442449	0.234	Welding-up
9	Critical	1.05752	0.351	Same
10	Same	0.604877	0.997	Mounting of sealing sleeve
11	»	0.930594	0.564	Welding-up
12	Significant	1.40803	0.137	Same
13	Same	1.188877	0.308	»
14	Insignificant	1.674394	0.0415	Grinding
15	Critical	0.9414836	1	Welding-up
16	Significant	1.224571	0.96801	Same
17	Critical	0.834522	1	»
18	Significant	1.107456	0.69741	»
19	Critical	1.014003	0.92865	»

Table 7. Priority of removal of model defects according to different ranking levels

Defect No.	At the time of diagnostics			After 1 year in service			After 2 years in service			After 3 years in service			Type of defect
	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	
1	3	12	14	3	15	16	2	14	16	1	14	16	Thinning
2	1	4	4	1	4	4	1	4	8	1	4	10	
3	3	19	19	3	19	19	3	19	19	3	19	19	
4	1	2	1	1	2	1	1	3	2	1	3	4	
5	1	1	3	1	1	3	1	1	5	1	1	8	
6	2	7	11	2	10	14	2	13	15	1	13	14	
7	3	18	18	3	18	18	3	18	18	2	18	18	
8	3	10	8	3	14	13	2	15	14	3	16	13	
9	2	5	5	2	5	8	1	7	11	1	9	11	
10	1	3	2	1	3	2	1	2	1	1	2	3	
11	3	11	6	2	6	7	1	5	9	1	6	9	
12	3	16	16	3	16	15	2	16	6	2	15	15	
13	3	14	12	2	12	12	2	12	13	2	11	12	
14	3	17	17	3	17	17	3	17	17	3	17	17	
15	2	8	9	2	9	5	2	8	3	1	7	2	Cracks
16	3	9	10	2	8	9	2	10	7	2	12	5	
17	2	6	7	2	7	6	1	6	4	1	5	1	
18	3	15	15	2	13	11	2	11	12	2	10	7	
19	3	13	13	2	11	10	2	9	10	1	8	6	

Table 8. Characteristics of defects of the type of local thinning in a region of «Urengoy-Centre 2» gas pipeline

Defect No.	s, mm	u, mm	$t_{\min}$, mm	Position in length of defect, m
1	330	200	16.0	2
2	210	200	16.8	250
3	350	350	15.7	450
4	400	350	15.1	600
5	380	460	15.5	900

Table 9. Characteristics of crack-like defects in a region of «Urengoy-Centre 2» gas pipeline

Defect No.	Crack	c, mm	a, mm	Position in length of defect, m
6	Longitudinal	110	1.60	10
7	Same	90	1.60	400
8	Circumferential	75	1.50	710
9	Same	150	1.55	820
10	Longitudinal	100	1.55	1000

Table 10. Probability of emergency situation with detected defects in «Urengoy-Centre 2» gas pipeline

Defect No.	Time of service, years				
	0	0.5	1.0	1.5	2.0
1	0 (8)	0.00025 (10)	0.0055 (9)	0.052 (9)	0.179 (9)
2	0 (8)	0 (12)	0.0015 (11)	0.0142 (10)	0.063 (10)
3	0 (8)	0.00125 (9)	0.026 (8)	0.131 (8)	0.338 (7)
4	0.0041 (5)	0.0562 (3)	0.240 (4)	0.490 (4)	0.758 (4)
5	0 (8)	0.007 (7)	0.0715 (7)	0.263 (7)	0.494 (7)
6	0.013 (1)	0.139 (1)	0.436 (1)	0.796 (1)	0.979 (1)
7	0.005 (2)	0.0962 (2)	0.269 (2)	0.600 (3)	0.864 (3)
8	0.001 (6)	0.0353 (6)	0.0612 (5)	0.462 (5)	0.720 (5)
9	0.004 (3)	0.054 (4)	0.251 (3)	0.317 (2)	0.9369 (2)
10	0.002 (5)	0.0412 (5)	0.177 (6)	0.419 (6)	0.715 (6)
11	0.005 (2)	0.005 (8)	0.005 (10)	0.005 (11)	0.005 (11)
12	0.001 (7)	0.001 (11)	0.001 (12)	0.001 (12)	0.001 (12)

Note. Priority of repair is indicated in brackets.

most dangerous regions (shown in grey) substantially decreases the accidence rate of MP.

Conclusions

1. The numeric approach to ranking of defects detected in IPD is suggested within the framework of development of the integrated procedure for planning of repair of MP without its removal from operation. The approach is based on multilevel analysis of the degree of damage of a pipeline in a specific region depending on the completeness of the available data on the actual state of a structure and specification requirements to its carrying capacity.

2. Differing conservatism of the developed procedure makes it possible to take into account, if necessary, specific features of the methods used for diagnostics of the state of linear parts of MP and characteristic peculiarities of their repair under pressure. In particular, the use of the probability estimation of admissibility of the detected defects suggests analysis of the natural spread of data on properties of the pipeline metal and defect parameters.

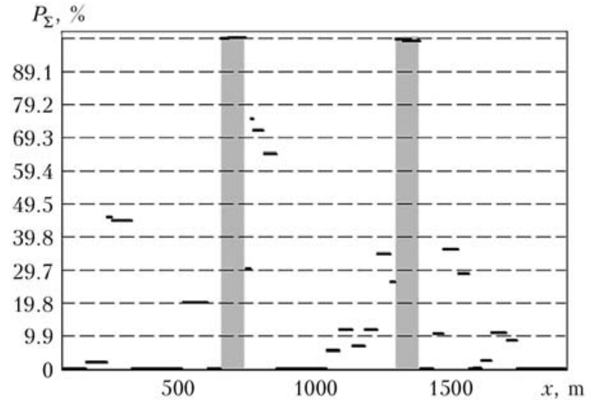


Figure 5. Distribution of total probability of emergency situation in a 10 m base region of bore pit in length of the investigated MP region

3. The limits of applicability of the developed procedure and specifics of the predicted devel-

opment of damage in terms of subsequent removal of defects by the methods of repair under pressure are shown by an example of a model problem of ranking of inadmissible defects of the type of local corrosion loss of metal and surface cracks, and on the basis of numeric analysis of the results of diagnostics of the state of the «Urengoy-Centre 2» gas pipeline region (Tables 8–10).

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